USGS
science for a changing world

Acoustic Flow Monitor System—User Manual

Open File Report 02-429

U.S. Deparatment of the Interior
U.S. Geological Survey

Front Cover:

Loowit Acoustic Flow Monitor installation above Loowit River with Mount St. Helens in background (U.S. Geological Survey photo)

Acoustic Flow Monitor System—User Manual

By Richard LaHusen

Open-File Report 02-429

U.S. Department of the Interior
U.S. Geological Survey

U.S. Department of the Interior
Gale A. Norton, Secretary

U.S. Geological Survey
P. Patrick Leahy, Acting Director

U.S. Geological Survey, Reston, Virginia 2005

For product and ordering information:
World Wide Web: http://www.usgs.gov/pubprod
Telephone: 1-888-ASK-USGS

For more information on the USGS—the Federal source for science about the Earth,
its natural and living resources, natural hazards, and the environment:
World Wide Web: http://www.usgs.gov
Telephone: 1-888-ASK-USGS

Suggested citation:
LaHusen, Richard, 2005, Acoustic Flow Monitor System—User Manual: U.S. Geological Survey, Open-File Report 02-429, 16 pages .

CONTENTS

Introduction 1
Overview 1
AFM main components 2
How the AFM Remote Terminal Unit works 3
How the AFM base station works 4
Appropriate use of the AFM system 4
Field station installation 4
Field site selection 4
Equipment installation 6
Install the secure vault 6
Install the antenna and solar panel 7
Install the geophone and preamplifier 7
Connect power components 7
Test procedures 8
Visual inspection 8
Testing with a PC for data display 8
Connect the PC to the radio modem 8
Test radio, cable and antenna 9
AFM quick test with a scanner 10
Station maintenance 10
Technical information 10
Connections to the AFM case 10
Data transmission format 10
System customization 11
Operating parameters 12
AFM command language 12
HyperTerminal software setup 14
Revision history 16
References 16

Figures

1. Schematic drawing showing main components of an AFM field installation 2
2. Schematic drawing of AFM sites along a channel and possible telemetry routing *A*. Direct AFM to base station; *B*. Through a streamside AFM with geophone; *C*. Through a dedicated hilltop repeater AFM without geophone 5
3. AFM case showing connections 9
4. Series of computer menus showing steps to configure PC software 14-15

TABLES

1. List of main components of an AFM field station 3
2. List of additional parts and equipment for field installations 6
3. Description of elements of data format 11
4. Explanation of parameters that can be modified 12
5. Explanation of AFM command language 13

CONVERSION FACTORS

SI to Inch/Pound

Multiply	By	To obtain
Length		
centimeter (cm)	0.3937	inch (in.)

Acoustic Flow Monitor System—User Manual

By Richard LaHusen

INTRODUCTION

The Acoustic Flow Monitor (AFM) is a portable system that was designed by the U.S. Geological Survey Cascades Volcano Observatory to detect and monitor debris flows associated with volcanoes. It has been successfully used internationally as part of real-time warning systems in valleys threatened by such flows (Brantley, 1990; Marcial and others, 1996; Lavigne and others, 2000). The AFM system has also been proven to be an effective tool for monitoring some non-volcanic debris flows.

This manual is intended to serve as a basic guide for the installation, testing, and maintenance of AFM systems. An overview of how the system works, as well as instructions for installation and guidelines for testing, is included. Interpretation of data is not covered in this manual; rather, the user should refer to the references provided for published examples of AFM data.

OVERVIEW

The AFM is a micro-powered field computer that monitors and analyzes the amplitude, frequency, and duration of ground vibrations caused by debris flows. These ground vibrations signal the approach of debris flows, fast-moving mixtures of rock debris, mud, and water that start on steep slopes and follow paths along stream channels.

The AFM system:

- Detects flows through vibrations—without physically contacting flows—which greatly reduces the need for hazardous maintenance trips
- Transfers real-time data to the base station
- Filters out noise that affects traditional seismographs
- Monitors multiple flows without intervention
- Allows field operating parameters to be changed from the base station
- Works well under extreme environmental conditions including ash and snow

AFM Main Components

The main components of an AFM field installation are illustrated in figure 1 and listed in table 1.

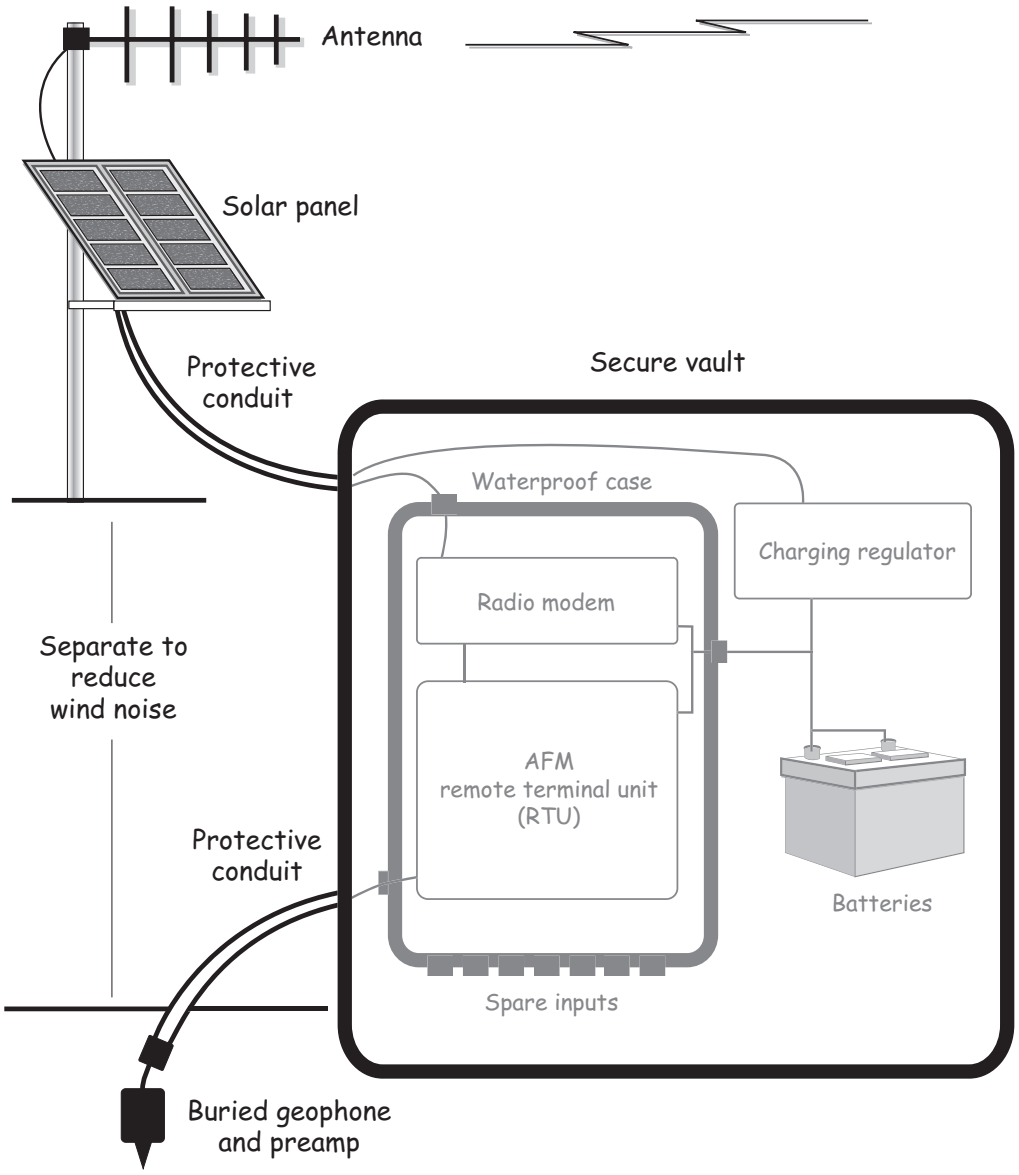


Figure 1. Main components of an AFM field installation.

Table 1. Main components of an AFM field station.

Component . . .	What it does . . .
AFM Remote Terminal Unit (RTU)	Continuously measures the amplitude and duration of ground vibrations. Sends data to the base station at regular intervals and sends immediate alert messages when detection criteria are met.
Radio Modem and Antenna	Transmits and receives data and commands between the RTU to the base station.
Solar Panel and Charging Regulator	Solar panel produces power to charge the battery. Regulator prevents overcharging and damage to the battery.
Battery	Supplies power to the system.
Geophone and Preamplifier	Senses, filters and amplifies ground vibrations with frequencies ranging from 10 Hz to 250 Hz
Secure Vault	Contains the RTU, Radio Modem, and Battery, and protects them from weather and physical damage.

How the AFM Remote Territorial Unit Works

The following steps describe how the AFM RTU detects, analyzes, and sends data:

1. **Detects ground vibrations.** The geophone converts ground vibrations to an alternating current (AC) signal and then the preamplifier filters and amplifies this signal. Finally, the signal is converted to a direct current (DC) signal before it is sent to the RTU.
2. **Analyzes the vibrations.** The RTU measures the signal amplitude and then compares it against alert "thresholds" for amplitude and duration in the RTU memory. Depending on the value of the signal ampl itude, two things can occur:
   - If the signal amplitude is below the threshold, the AFM sends normal, unflagged data to the base station at timed intervals (usually every 10 minutes).
   - If the signal exceeds the alert thresholds for amplitude and continuous duration, the AFM switches to alert mode, sending an immediate flagged data report that repeats at one-minute intervals. When the signal amplitude drops below the threshold, the AFM resumes normal operation.
3. **Sends data.** The UHF radio modem transmits the data to the base station via the antenna. Each unit can simultaneously serve as a telemetry repeater for other stations.
4. **Responds to commands.** If a valid command is received, the RTU will fulfill the command to send data, repeat a message, or load new operating parameters.

◆ **Note:** The default alert values for the AFM are 500 mv for 40 seconds on the first input channel. The threshold value, duration and channel can be changed for custom applications via commands sent from the base station.

How the AFM Base Station Works

The base station consists of a personal computer (PC) with a serial connection to a radio-modem and antenna for sending and receiving messages from AFM field units. The base station PC can run any software program that meets the requirements of the specific application. Typically, the base program logs and displays data sent from the field stations. The program should also verify integrity of each data message using transmitted checksums and issue alerts as needed. Several custom programs have been written for AFM system operation but off-the-shelf programs are also suitable. Numerous commercial software products using OPC (Object Linking and Embedding for Process Control) standards are available. For more information about OPC compliant products, see the OPC foundation website at ***www.opcfoundation.org***.

Appropriate Use of the AFM System

The AFM is primarily intended as an early warning system for debris flows associated with volcanic eruptions. These debris flows usually take considerable time to travel before coming in contact with populated areas. When properly installed as part of a comprehensive public defense program, the AFM system provides a fast and reliable debris flow alert, giving people enough time to seek safety. An AFM system can only be effective as one element of a comprehensive civil defense program.

The AFM system should not be used to warn of fast moving flows that form near populated areas where there is little or no time to alert people.

FIELD STATION INSTALLATION

Field Site Selection

To successfully detect sediment-laden flows, AFM field stations must be located adjacent to channels where debris flows might pass. Geophones should be located about 50 meters above the maximum anticipated debris flow inundation level. The uppermost site should be as far upstream as possible to maximize warning time. Additional sites should be located downstream to confirm the size and speed of the flows. Figure 2 shows typical AFM sites along a channel.

Consideration should also be given to select field sites that allow proper electrical operation of the stations. The solar panel should have unobstructed view of the sun and every station should have a line-of-sight radio transmission path to the base station or a telemetry repeater. Each AFM unit can repeat data and messages to and from other stations. Figure 2 illustrates three possible telemetry routes from field station to base:

A. Direct from AFM field station to base

B. Through another stream-side AFM

C. Through a hilltop AFM station as a dedicated repeater

◆ **Note:** Choose sites that are easy enough to access for repairs and maintenance, yet difficult enough to discourage vandalism or theft. In easily accessible areas, the help of local residents or a strong secure vault may be needed to keep the AFM field station secure.

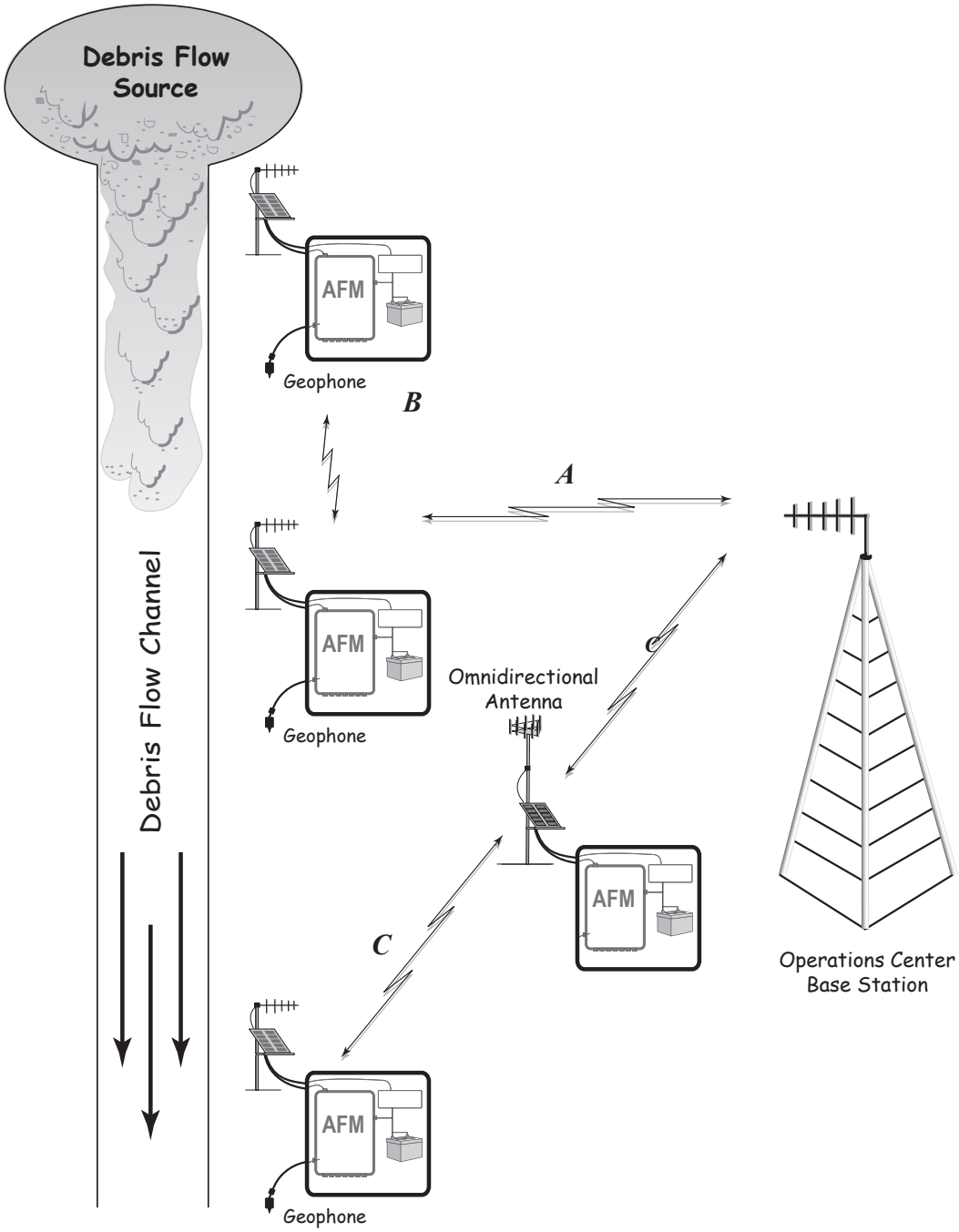


Figure 2. AFM sites along a channel and possible telemetry routing: *A*. Direct AFM to Base; *B*. Through a streamside AFM with geophone; *C*. Through a dedicated hilltop repeater AFM without geophone.

Equipment Installation

Once you've selected an appropriate site, you're ready to install the AFM. Be sure to refer to table 2 for additional equipment you may need for your installation. The following list includes the AFM components you'll be installing:

- Secure vault
- Radio antenna and mast
- Solar panel
- UHF radio modem
- AFM case
- Geophone and preamplifier
- Grounding rod – connect to battery ground
- Battery and charging regulator

◆ Note: Be sure to test the AFM in the lab to verify it is working properly before you install it in the field. For instructions on how to perform the AFM tests, see section on test procedures

Table 2. Additional parts and equipment for field installations.

- Antenna mast and mount
- Power and serial cables
- Electrical grounding rod, clamp and cable
- Conduit and wire cloth for cable protection
- Shovel or auger to bury geophone
- Battery terminal coating (petroleum jelly)
- Radio scanner for quick field tests
- RF watt meter to test radio, antenna and cable

Install the Secure Vault

The secure vault can be any appropriate container that protects the AFM from direct exposure and potential vandalism. For example, it could be a locked concrete or steel box that is fastened to the earth, or simply a large ice chest or steel drum, depending on climate and site visibility. To install the secure vault:

1. Clear and prepare the vault area. (Make sure to leave ample room around the vault to perform future repairs and maintenance.)
2. Place the vault in position.
3. Place the battery in the vault.
4. Drive a grounding rod beside the vault, and connect a cable from the rod to the negative terminal of the battery for lightening protection.
5. Place the AFM case and battery inside the vault.

Install the Antenna and Solar Panel

1. Install a mast for the antenna and solar panel.
2. Mount the antenna on the mast, with the elements of the antenna vertically oriented.
3. Connect the antenna cable to the antenna, and seal the connection to make it waterproof.
4. Connect the antenna cable to the RTU case.

> ◆ **Note.** Enclose ***all*** cables running to and from the secure vault in a protective metal conduit, and then bury the conduit in the ground; this will prevent animals and weather from damaging the cables. To protect small areas of exposed cable, cover them with a stiff wire cloth.

5. Mount the solar panel on the mast so it faces toward the equator at an angle equal to the latitude plus 15 degrees.

   In areas that will receive ash or snow, use a steeper angle to help keep the panel clear. In extreme cases, the AFM field station can operate solely on batteries.

Install the Geophone and Preamplifier

1. Choose a location for the geophone about ten meters from the antenna mast, to avoid vibration noise produced by wind shaking the antenna and mast.
2. Dig a hole 60 to 100 centimeters deep.
3. Press the geophone into the bottom of the hole, then pack dirt around the geophone and preamplifier; continue to add firmly packed dirt until the hole is filled.
4. Connect the geophone cable to the AFM case inside the vault.

Connect Power Components

1. Connect the charging regulator to the solar panel output and the battery.
2. Connect power cord to AFM case.

> ◆ **Caution.** Make sure to follow the directions included with the charging regulator. If connected wrong, it could damage the AFM.

TEST PROCEDURES

Each station should be inspected and tested following shipment and prior to field installation.

Visual Inspection

Before you begin, make sure that all AFM components, parts, and equipment are present, and inspect the system for any damage that may have occurred during shipping:

- Visually inspect the AFM for broken, missing or loose pieces.
- Verify that all connections inside and outside the AFM case are clean secure.
- Verify that each integrated circuit (IC) is firmly seated in its socket.
- Close the air vent on the front of the AFM case to make the case watertight.

Testing with a PC for Data Display

This test may be performed to insure that the AFM is working properly before you install it in the field or after installation if you have a laptop PC in the field, or voice communication with the base station PC operator. To perform the test you'll need:

- Geophone and preamplifier
- Antenna or "dummy" load
- Radio modem
- AFM case with components internal components
- Computer (PC) with Windows HyperTerminal and an RS232 serial port

Connect the PC to the Radio Modem

1. Connect an antenna or "dummy" load to the radio modem case.

> ◆ **Caution.** To prevent radio damage, always connect an antenna or "dummy" load to the radio before turning it or the AFM unit on.

2. Connect the serial cable between the radio modem and the PC Com port.
3. Connect a power cord to a 12-volt DC supply and the radio modem case.
4. Configure terminal emulation software as specified in Technical inforation section of this document.

Follow the steps below to set up and test the AFM unit. Refer to figure 3 for connection locations.

1. Connect an antenna to the AFM case.
2. Connect the geophone and preamplifier to the first sensor input connection, and then lay the geophone on a soft surface so it won't send vibration data.
3. Set the AFM station identifier switch (SW1 located inside the RTU) to the ID value for that station. Set SW2 to the repeater ID to be used by this station or set SW2 to same setting as SW1 if no repeater is to be used.

4. Connect the power cord to a 12-volt DC supply and the AFM power input connection.

   When the power is on, the RTU immediately sends a ***normal*** data set to the computer.

5. Hold the geophone upright, and gently tap it for 40 to 60 seconds.

   The RTU sends an ***alert*** data set to the computer

   Lay the geophone back down on a soft surface, and allow the RTU to run for at least an hour to verify that ***normal*** timed transmissions occur.

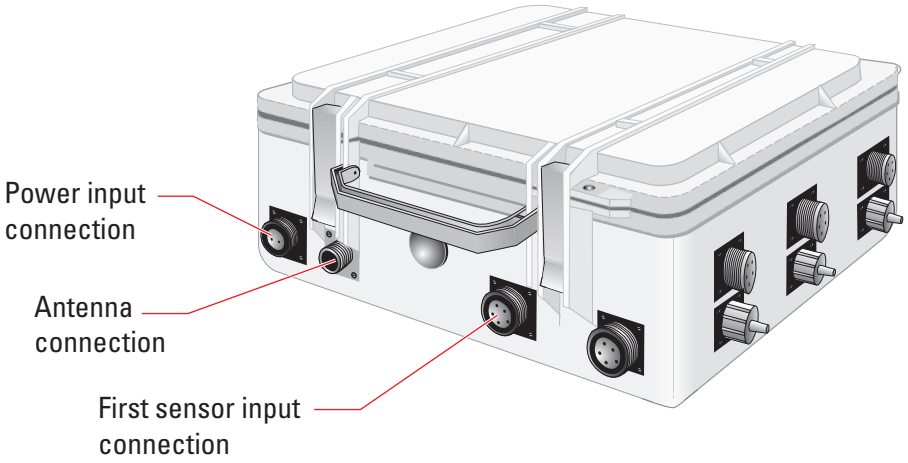


Figure 3 AFM case showing connections

Test Radio, Cable and Antenna

- Connect the RF wattmeter between the AFM antenna connection and the antenna cable according to manufacturers instructions. Set the RF wattmeter to measure power out.
- Connect the AFM power cable to the battery, then to the AFM power input.
- During a power-on transmission, verify that the radio is putting out the proper amount of power, typically 1 to 4 watts depending on radio model used
- Disconnect power from the AFM.
- Set the RF wattmeter to measure reflected power or standing wave ratio (SWR).
- Reconnect power to the AFM; the meter should read little or no reflected power (SWR < 1.5).
- Disconnect power from the AFM, and then remove the RF wattmeter.
- If problems are found, check radio, antenna and coax cables.

◆ **Important.** After installation and testing are complete, make sure to coat ***all*** exposed power connections with a battery terminal coating or petroleum jelly to make the connections waterproof and prevent corrosion.

AFM Quick Test with a Scanner

The AFM quick test can be used in the field to verify that the RTU is operating and transmitting data. To perform the quick test, you can use a radio scanner to hear transmissions from the AFM field station.

1. Set the scanner to your system's frequency, adjust volume and squelch as needed.
2. Set up the AFM (as described in installation section), and then apply power to the unit.
3. Listen to the scanner.

   You should hear the RTU sending a ***normal*** data report during power up and initialization.
4. Hold the geophone upright, and gently tap it for 40 to 60 seconds. If the geophone is already buried, you can forcefully stomp the ground over the sensor for 40-60 seconds.

   You should hear the RTU sending another data report that is an ***alert*** report.

STATION MAINTENANCE

Little maintenance of field stations is needed when careful installation and a little preventive maintenance to applied. Most common problems can be avoided if exposed terminals have an airtight coating to prevent oxidation and cables are protected with conduit or wire cloth to prevent animal damage. Annual inspections at each field station are recommended to keep the AFM functioning properly. Flooded-cell lead-acid batteries should have the fluid level checked and should be filled with mineral free water to prevent battery damage and all batteries should be replaced before the end of their useful life

If a faulty RTU is encountered, please contact USGS, Cascades Volcano Observatory, Vancouver, WA USA, for evaluation and replacement.

TECHNICAL INFORMATION

Connections to the AFM Case

Power connector. Connection to the two pin plug on the are as follows: Pin A is positive 12 volts DC at 2 amps peak, Pin B is ground.

Analog Inputs. Connection to the 5 pin analog input plugs are as follows: Pin A is unswitched, unregulated 12 volt battery power output to the sensor, Pin B is common ground, Pin C is analog signal input +/- 4 volts, Pins D and E are unused. Input channels are sequentially positioned on the AFM case from left to right, top to bottom.

Radio. Antenna connector is 50 ohm, type N.

Data Transmission Format

The AFM data format is compatible with software provided by the USGS and with a variety of OPC data servers (Object Linking and Embedding for Process Control). For more information about OPC, visit the OPC foundation at ***www.opcfoundation.org***.

Data from the AFM field units are transmitted to the base station in the following format::

AST +0000 +0001 +0002 +0003 +0004 +0005 +0006 +0007 c+CKSM<CR>

The following table describes the elements of the above data format.

Element . . .	What it means . . .
A	A one character alert status—'0' for non-alert, and '1' for alert
ST	A two digit station ID from, 00 to 15
+000(0-7)	Space-delimited signed values from each of the eight analog channels, in millivolts.
c	Character delimiter between data string and checksum.
+CKSM	A 16-bit decimal checksum for ASCII values up to and including the 'c' character (**NOTE.** Base station software should calculate the checksum, and then compare this value to the transmitted value to insure message integrity.)
<CR>	Indicates a carriage return (line termination)

System Customization

Most installations will not require any modifications to the default operating parameters of AFM field stations. However, it is possible to modify the remote stations under unusual circumstances. These modifications can be made remotely from the base station by forming and sending the appropriate command. The technical information presented in this section is not intended for a novice user.

◆ **Note.** Only persons who are experienced and proficient in the operation of AFM system components should attempt to change the default operating parameters. If a serious mistake is made, a site visit may be needed to restore operation of a remote station by repowering the unit.

Some reasons for changing operating parameters may be:

- Increase or decrease reporting frequency
- Increase or decrease sensitivity for detecting debris flows
- Polled operation (requests from base station for data)
- Switch to an alternate sensor channel for alert monitoring
- Turn off malfunctioning station or sensor

Operating parameters

The following table explains the parameters you are able to modify. You can modify parameters by using the AFM command language. For examples on how to use the this language, see the section on *AFM command language*.

◆ **Note.** All numerical values sent in AFM commands are transmitted as hexadecimal values.

Parameter . . .	What it controls . . .
XINT	Transmission intervals in minutes, stored as a 1-byte value starting at location 90h. The range is from 1d to 59d, with a default value of 10d. (**Note.** The more frequent the reporting, the more power is used.)
XTIME	RTU time in minutes for the next unsolicited data report, stored as a 1-byte value at location 91h. To operate with no unsolicited messages, set this parameter to 61d; alert transmissions will still be active, but no non-alert reports will be generated.
THRESHOLD	The minimum sustained amplitude of ground shaking required for an alert, stored as a 2-byte value at location 84h. The default value is 500d. (**Note.** This value can be reduced if background noise is low and the geophone is located far from the channel.)
DURATION	The time (in seconds) that ground-shaking amplitude must exceed the THRESHOLD to trigger an alert, stored as a 1-byte value a location 8Ch. The default value is 45 seconds. (**Note.** This is the best parameter to increase to avoid alerts due to environmental factors, such as wind, thunder, etc.)
TRCHAN	Specifies which analog input will trigger an alert based on THRESHOLD and DURATION, stored as a 1-byte value at location B6h. The default channel is 01h. (**Note.** This value can be switched to another channel if the primary sensor fails, or if more or less gain is needed.)

AFM Command Language

With the AFM command language you can verify or modify operating parameters from their default values, or poll each station for data reports. Each command adheres to the following format:

!SCdata*

In this format:

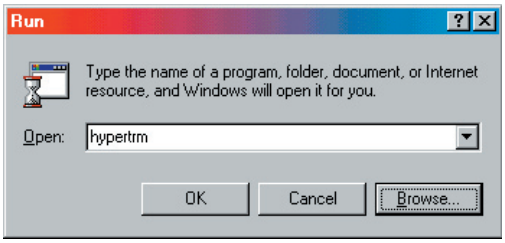
- Each command begins with a "!" and ends with a "*"
- "S" is the ASCII station ID character for the target station (0-9, A-F)
- "C" is a single character command (J, D. L, R)
- "data" is a string consisting of a hex address and hex count (in the Dump, Jump, and Load commands) or a repeated string (in the Repeat command).

Command . . .	What it does . . .
J (jump)	Instructs the RTU to jump to FE10, the hex address that causes the station to immediately transmit a standard data scan. **Example:** ***!1JFE10,10**** commands station 1 to jump to program address FE10 and transmit the data.
D (dump)	Transmits values stored in memory as space-delimited hex bytes. This can be used to verify operational settings. **Example:** ***!2D0084,10**** commands station 2 to transmit the 16 values from locations 0084h to 0094h (key operational settings).
L (load)	Places hex values in locations. The format is: ***!SLAAAA,BB:hexdata****, where: • **AAAA** is the beginning hex memory address • **BB** is the number of bytes to be loaded into memory registers starting at AAAA • **hexdata** are BB bytes of hex data to be loaded into memory **Example:** ***!3L008C,01:5A**** commands station 3 to load 5Ah into memory addresses starting with location 008Ch. This command would set the DURATION parameter to 90d (5Ah) seconds.
R (repeat)	Repeats the rest of a string after “R” and up to “*”. **Example:** ***!4RHelloWorld**** commands station 4 to transmit the string “HelloWorld”. Multiple repeats are chained within a message to form a routing prefix for messages such as ***!2R!3R!4JFE10,10****

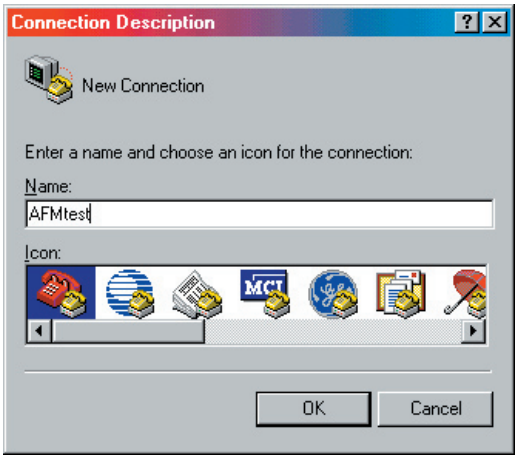
HyperTerminal Software Setup

The following steps describe how to configure your PC software to receive test data from the RTU.

1. From the Windows task bar, click Start, then click Run.
2. Type “hypertrm,” then click OK.

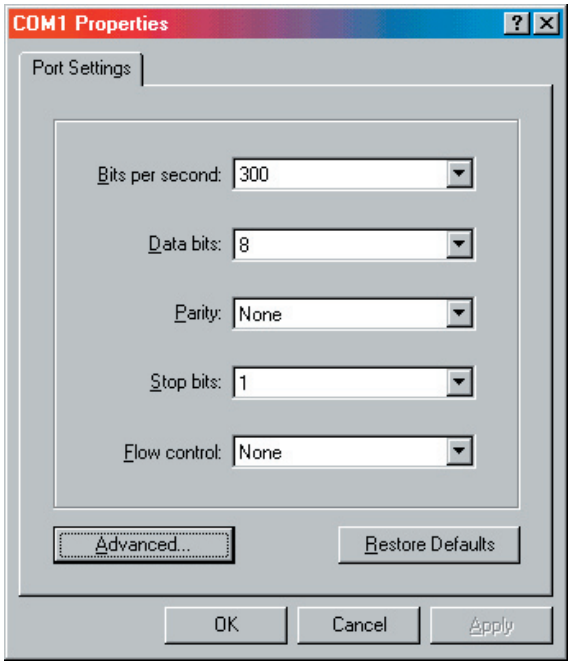


3. In the Connection Description dialog box, type “AFMtest” to save this setup for future use, then click OK.

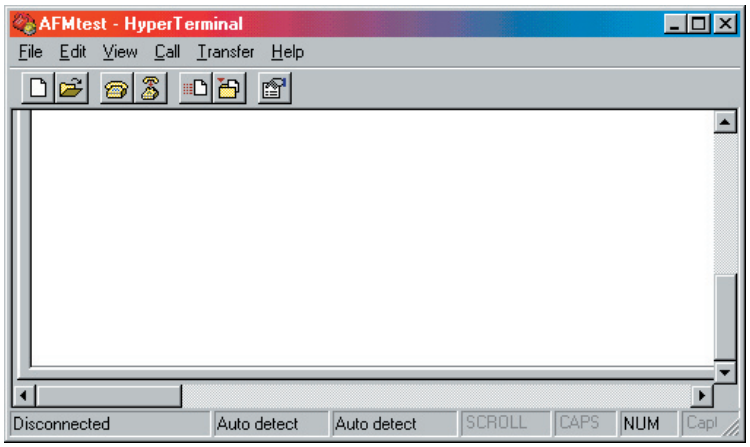


4. In the Connect To dialog box, select “Direct to Com1” from the Connect using drop down list, then click OK.

5. Configure the COM1 port settings as appropriate, then click OK.



6. You will see a Hyper Terminal display screen:



Your PC software is now ready to receive and display test data from the RTU.

Revision History

The following major hardware versions have been released:

- **Preamplifier circuits.**. The geophone conditioning circuits are enclosed in a short length of 2.5 cm PVC pipe; these enclosed circuits are not serviceable. Two versions of the preamplifier circuit have been used:
  1. AC output amp is used with Version C RTU circuits
  2. DC output amp is used with the Version D RTU circuits
- **Circuit board set (experimental version).** The original installations of AFMs documented in Hadley and LaHusen, 1995 consisted of 3 separate circuit cards:
  1. CPU/modem card,
  2. Analog I/O card,
  3. Analog signal conditioning card.
- **Circuit board (version C).** This circuit board is composed of a single circuit card optimized for AFM applications only. It has a integrated Bell 103 modem with transformer coupling for connection to analog radios. Signal conditioning for a single AC output geophone is included onboard. The card is mounted in a 12 cm x 18 cm x 5 cm aluminum box with a 9 pin D connector for both power and 8 analog inputs.
- **Circuit board (version D).** This circuit board is a multi-function card mounted in an 18 cm x 18 cm x 5 cm aluminum box, with separate connections for power, serial digital communications, analog and digital inputs and outputs. Serial baud rate is jumper adjustable. Version D cards send the battery voltage as the first value in a data line (analog channel 00). Multiply this telemetered value by .004 to obtain the current battery level in volts. Multiple geophones can be used at a single station using the DC output geophone preamplifiers.

REFERENCES

Brantley, S.R. ,ed. 1990, The eruption of Redoubt Volcano, Alaska, December 14, 1989 - August 31, 1990: U.S. Geological Survey Circular 1061, 33 p.

Hadley, K.C. and LaHusen, R.G., 1995, Technical manual for an experimental acoustic flow monitor: U.S. Geological Survey Open-File Report 95-114, 26 p.

F. Lavigne, J.-C. Thouret, B. Voight, K. Young, R. LaHusen, J. Marso, H. Suwa, A. Sumaryono, D.S. Sayudi, M. Dejean,, 2000, Instrumental lah ar monitoring at Merapi Volcano, Central Java, Indonesia, Journal of Volcanology and Geothermal Research, 2000, V 100, N 1-4, July., pp. 457-478

Marcial, S.S., Melosantos, A.A., Hadley, K.C., LaHusen, R.G., and Marso, J.N., 1996, Instrumental lahar monitoring at Pinatubo Volcano: IN: Newhall,C.G. and Punongbayan, R.S. eds., Fire and Mud: Eruptions and Lahars of Mount Pinatubo, Philippines: Phillippine Institute of Volcanology and Seismology, Quezon, City and University Press, Seattle, p. 1015-1022.